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LONGER DELAYS FROM FUSED-QUARTZ DELAY LINES BY MULTIPLE PASSAGE TECHNIQUES

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INTRODUCTION

Long-range, shipboard, search radars employing moving target indication (MTI) use mercury delay lines with delays of 2000 to 4000 μsec as signal-storage devices. Although the techniques involved in the design and construction of mercury delay lines are highly developed, the delay lines have some undesirable characteristics. Since they use considerable mercury, they are heavy. The physical characteristics of mercury make it difficult to confine in a delay line, and it must be held under pressure to prevent cavitation. When this condition occurs, the signal is lost either momentarily or for long periods of time. The pressure required to prevent cavitation necessitates a large, heavy structure that is mechanically complex and expensive to manufacture.

Besides these undesirable mechanical characteristics, experience has indicated that after a mercury delay line has been in use (filled with mercury) from one to three years the mercury forms an amalgam on the walls of the line even though they are made of stainless steel. It is extremely difficult to remove this amalgam without remachining the line, but unless removed it will quickly contaminate clean mercury used to refill the delay line, and signal losses will increase until the line is practically useless. In view of these characteristics, there can be no question that a smaller, lighter, and more trouble-free delay device would be desirable and advantageous.

Recent improvements in fabrication techniques for the quartz delay line[1] have resulted in a light and compact low-loss line that presents no contamination or cavitation problems. This device seems to be the solution for some of the difficulties presented by the mercury delay line and may possibly replace it. At present, the one disadvantage of the quartz line is that it is not economical to construct with delays of more than 1000 to 1800 μsec. This limitation is caused by difficulty in producing sufficiently large and pure quartz slabs.

Since the quartz delay line[2] (Figure 1) available to the Naval Research Laboratory had a delay time of 1005 μsec, it was necessary to use it more than once to achieve effective delays of nominally 2000 to 4000 μsec which would be required in search radars having prf of 250 to 500 per sec. Two methods were developed and tested to effectively stretch the delay time. Both are recirculation schemes in which the signals are passed through a single delay line more than once; one does so by frequency separation and the other by time separation. In a third method considered, multiple delay lines are used.

FREQUENCY-SEPARATION METHOD

The frequency-separation method involves a double frequency conversion whereby a signal is passed through the quartz delay line two or more times at a different frequency each time. As set up for tests, the system recirculated the signal four times to obtain a 4000-μsec delay.

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[1] *The design and development of the quartz delay line has resulted largely from the efforts of the U.S. Naval Air Development Center, Johnsville, Pa.*

[2] *The quartz delay line used in these investigations was loaned to this Laboratory by USNADC, Johnsville, Pa.*

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This method, the circuits of which are shown in Figure 2, operates as follows: A 12.5-Mc input signal is fed through the quartz delay line, delayed 1000 μsec, and then fed into the converter (Figure 3) where it is converted up to 64.5 Mc and back down to 14 Mc. The output of the converter is fed into the delay-line unit (Figure 4) where it is amplified and again passed into the quartz delay line; here, the signal is delayed another 1000 μsec and the total delay is then 2000 μsec. To obtain a total delay of 4000 μsec, the signal is passed through the converter and through the amplifier and quartz delay line two more times at frequencies of 15.5 and 17 Mc. After being picked off in a 17-Mc pick-off amplifier (Figure 5) where it is amplified and detected, the signal is ready to go into the cancellation unit of MTI for comparison with an undelayed signal.

Tests of this method disclosed that the 4000-μsec delayed signal was about 25 db higher in level than any spurious signal generated. Since the spurious responses of the quartz delay line[3] were about 25 db below the delayed signal, the quartz delay line was considered the limiting factor. It was found that by adjusting the frequency of the 50.5-Mc second oscillator the delay time of this method could be made 2000, 3000, 5000, or 6000 μsec as well as 4000 μsec. When adjusted for 5000- and 6000-μsec delays, however, the spurious responses were appreciably increased.

To reduce spurious responses to a minimum, the frequencies at which the double conversion was performed were carefully selected to obtain the desired frequency separation of the signals without interference from harmonics of the signals or the converter oscillators. The circuits were also laid out to give maximum isolation and shielding. As another precaution to prevent harmonic generation, all amplifiers were operated linearly and all signal levels were maintained low enough to prevent nonlinear operation. To illustrate the necessity of such precautions, high-level trigger pulses generate spurious responses that have as high a level as the trigger pulses.

TIME-SEPARATION METHOD

In the time-separation method, the circuit of which is shown in Figure 6, MTI information is presented for only a portion of the radar cycle. The portion or range over which information is presented is determined by the delay time of the delay line; for example, with the 1000-μsec quartz delay line, information would be presented for 1000 μsec or an 82-mile range. This period of information presentation could be positioned in any part of the radar cycle; in the circuit used to test this method, the information was presented in the first part of the radar cycle, that is, 0 to 82 miles.

With the start of a radar cycle, the trigger unit (Figure 7) fires a pulse to the remodulator (Figure 8), and a pulse is sent simultaneously to the video switch unit (Figure 9) which turns on the input video amplifier and turns off the recirculating video amplifier. A coherent input video signal can then pass through the input video amplifier into the remodulator. The 15-Mc modulated carrier out of the remodulator is fed through the quartz delay line into the delay-line post amplifier (Figure 10), which has an i-f channel for the video i-f and another for the high-level trigger pulses. One of the outputs from the post amplifier is a coherent video signal delayed 1000 μsec and the other is a trigger pulse (also delayed 1000 μsec) which is fed into the trigger unit actuating it; a new master-trigger pulse is thus generated. This trigger pulse, fed simultaneously into the remodulator and the video switch unit, turns off the input video amplifier and turns on the recirculating video amplifier. The coherent delayed video can then pass through the recirculating video amplifier, the remodulator, the quartz delay line, and the post amplifier a second time and becomes a coherent video signal delayed 2000 μsec. The trigger pulse, which was fed into the remodulator, also goes through the delay line, post amplifier, and into the trigger unit and actuates it to again form a new master-trigger pulse. The input video amplifier is turned on and the recirculating video amplifier is turned off by the pulse. A new coherent input video signal is thus allowed to go through the input video amplifier, the remodulator, and into the thru video and cancellation unit (Figure 11) at the same time the delayed coherent video signal is fed into the cancellation unit. These two signals are compared; the residual becomes the MTI video signal and is presented in the

[3] *Quartz delay lines have been improved so that spurious responses are about 35 db below the main response.*

first part of the radar cycle. No information is presented during the remainder of the cycle since the coherent signal that has been delayed 1000 μsec goes into the thru video and into the cancellation from the remodulator at the same time it is going into the cancellation unit from the post amplifier; the signal thus cancels itself.

The master-trigger pulses used to gate the input and recirculating video amplifiers on and off are also counted down two to one in the video switch unit. Since the pulse-repetition frequency of the master-trigger pulses is controlled by the delay time of the delay line, it is 1000 pulses per second. When counted two to one, these pulses become the modulator trigger pulses at 500 pulses per sec.

In this method, the video-switch circuit is the only one that is not normally used in MTI systems; therefore, only the detailed operation of this one circuit will be discussed.

A pulse from the trigger unit is fed into a video amplifier that consists of stages V-7A and V-7B. By cathode injection, the output of the video amplifier serves as a trigger for a flip-flop consisting of stages V-8A and V-8B. The plates of both flip-flop stages are coupled to the grids of buffer stages V-9A and V-9B so the conducting stage of the flip-flop will force the buffer stage connected to it into nonconduction. For example, if V-9A is nonconducting and V-9B is conducting, the rise in plate voltage of V-9A will cause the clamping diode stage V-6A to conduct and the suppressor of one of the gating stages V-3 will be biased into conduction. At the same time, the drop in plate voltage of V-9B will drive the suppressor of gating stage V-4 negative into nonconduction since the diode stage V-6B will remain nonconducting. The next trigger pulse from the trigger unit will reverse the condition of the flip-flop which in turn will reverse the condition of the gating tubes. This reversal allows the video signals from input-video stages V-1 and V-2 to be alternately gated on and off. The output of the gating tubes is fed into a cathode follower, the output of which is fed to the remodulator unit.

In addition to being coupled to buffer stage V-9B for gating, the plate of the flip-flop stage V-8B is connected through a differentiator network into a clamping stage V-10A. This stage eliminates the positive portion of the differentiated pulse, amplifies only the negative portion, and thereby gives a positive pulse output. Thus, a complete cycle of the flip-flop or two pulses from the trigger unit are required to produce one trigger pulse out of the clamping tube. The positive output of the clamping stage is fed into a cathode follower, V-10B, the output of which becomes the modulator trigger pulse.

Although tests of this recirculation method gave fair results (about 20 db) as far as cancellation ratio was concerned, it was subject, nevertheless, to severe gating transients and has the disadvantage of supplying information for only a part of the radar cycle.

MULTIPLE DELAY LINES

The third and obvious method to obtain the required delay time for a particular MTI system is to use more than one quartz delay line. This method was not set up and tested because only one quartz delay line was available, and it was felt that the circuits involved[4] were so simple and straightforward that no difficulties would be encountered.

CONCLUSIONS AND RECOMMENDATIONS

As a result of tests and investigations, the multiple-delay-line method was concluded to be the most satisfactory way of using quartz delay lines in search-radar MTI systems.

The recirculation-frequency-separation system was critical of adjustment and would probably be difficult to adjust and maintain in fleet use. This method, however, did have flexibility since by adjusting one oscillator frequency, the delay times could be changed in multiples of delay-line delay time.

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4 *A two or three stage amplifier with a gain of 45 to 50 db following each delay line would be required to make up for losses in the line.*

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Of the three methods, the recirculation-time-separation method had the least to offer since it not only showed severe gating transients but also supplied the information for only part of the radar cycle.

The multiple-delay-line method was the most promising because it was simple and required no additional circuits (other than the booster i-f amplifiers) for replacement of mercury delay lines.

It is recommended that commercial production be encouraged for high quality quartz suitable for use as delay lines.

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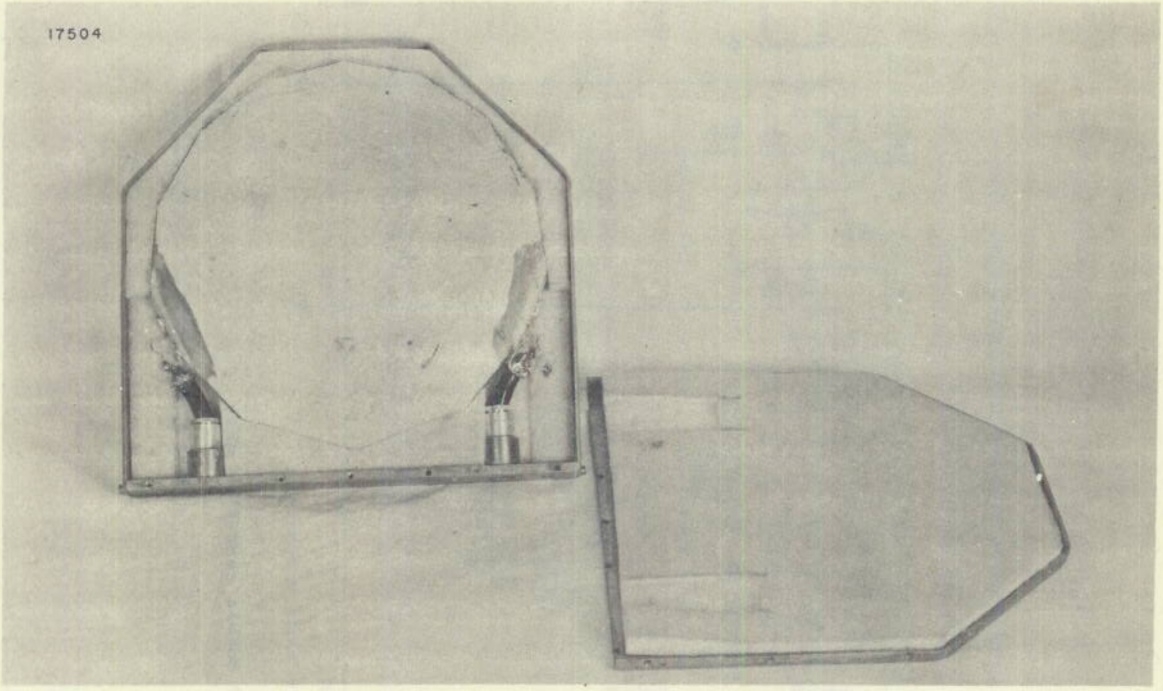

Figure 1 - Quartz delay line

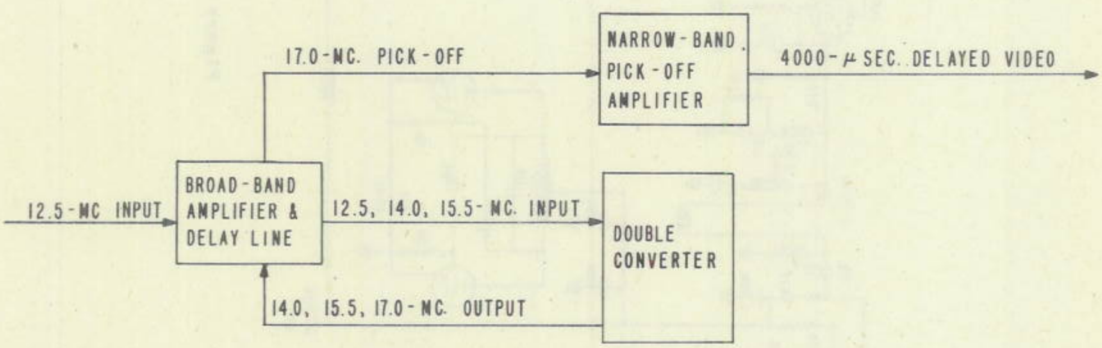

Figure 2 - Block diagram of frequency-separation method

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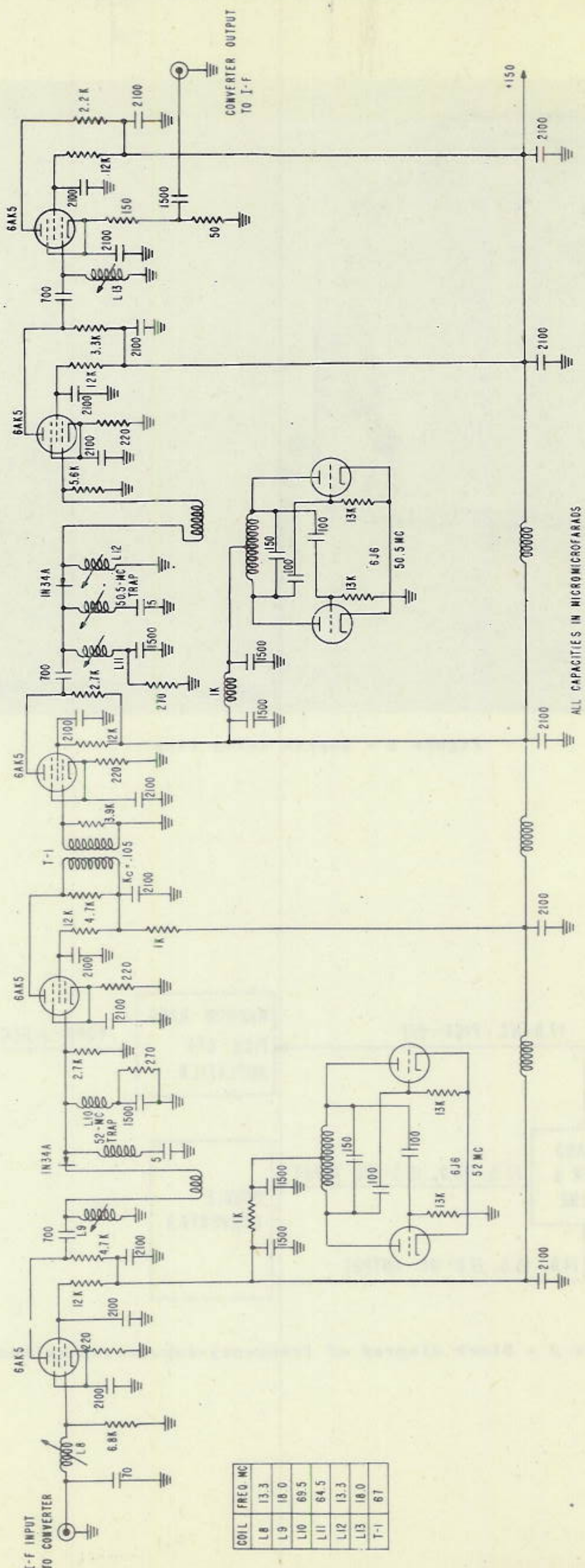
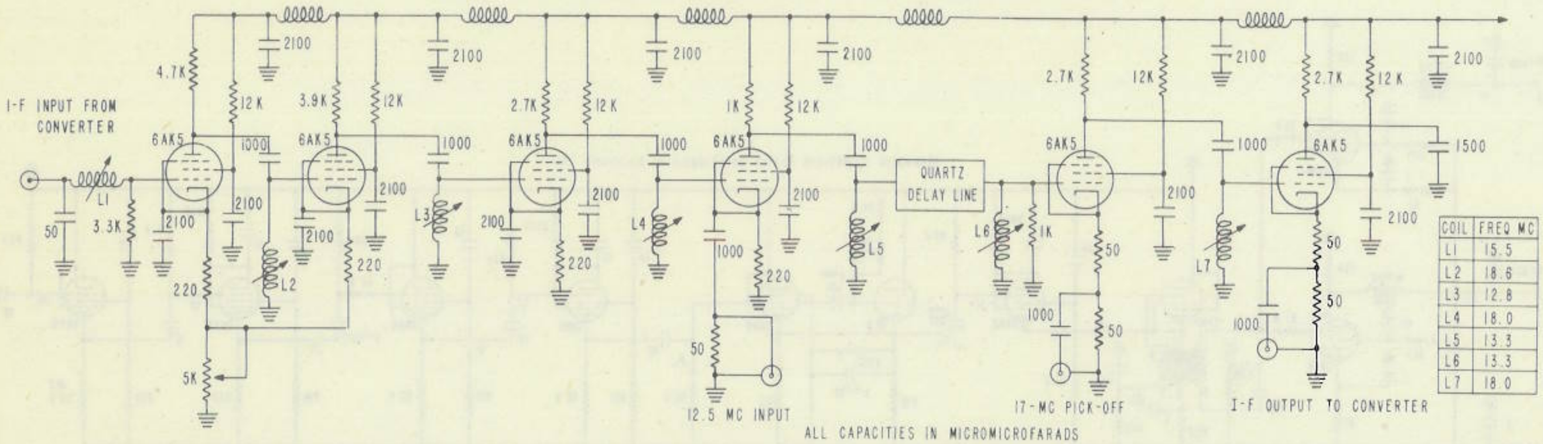


COIL	FREQ MC
L8	13.3
L9	18.0
L10	69.5
L11	64.5
L12	13.3
L13	18.0
T-1	67

Figure 3 - Circuit diagram of double converter unit

[redacted]

[redacted]



COIL	FREQ MC
L1	15.5
L2	18.6
L3	12.8
L4	18.0
L5	13.3
L6	13.3
L7	18.0

Figure 4 - Circuit diagram of broadband i-f amplifier and delay unit

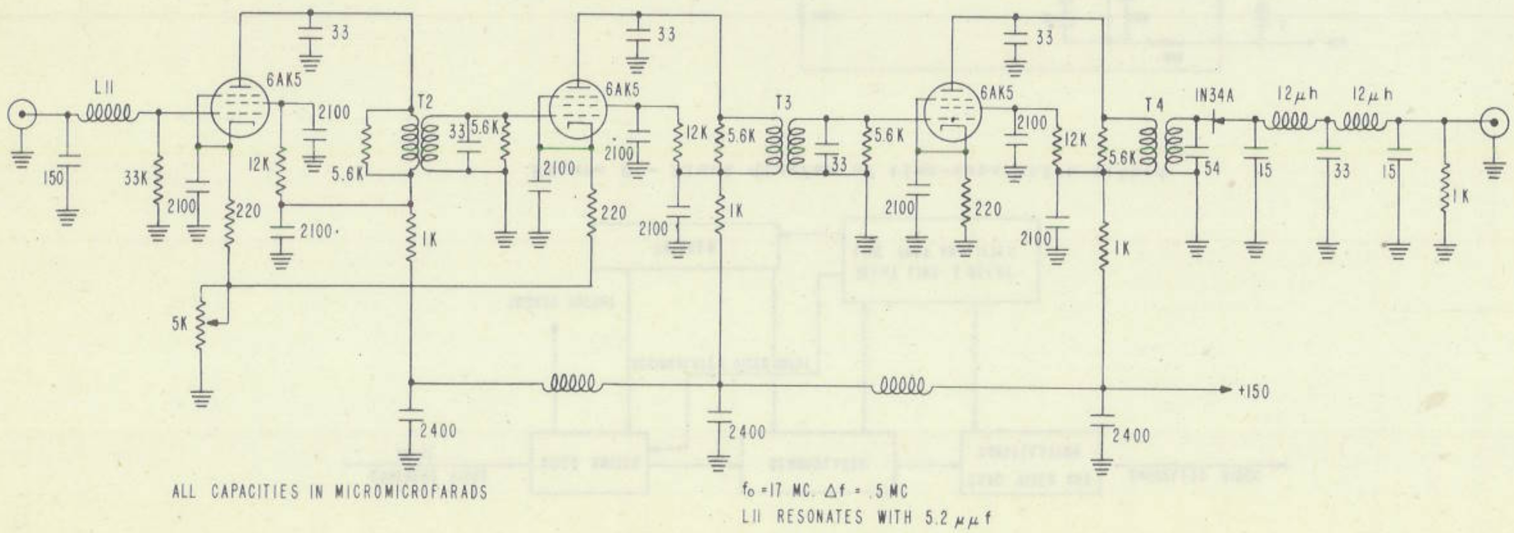


Figure 5 - Circuit diagram of i-f pick-off amplifier and detector unit

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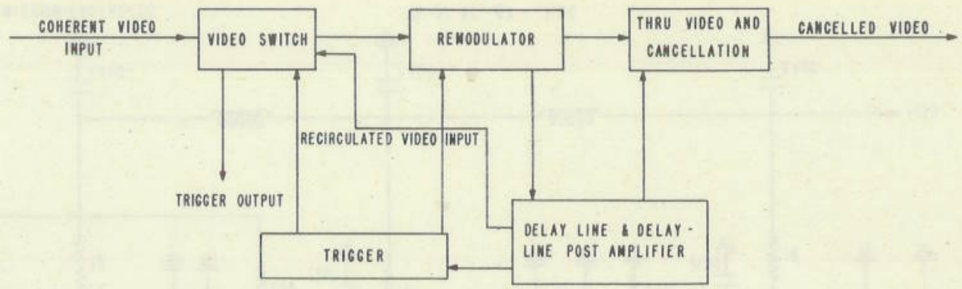

Figure 6 - Block diagram of time-separation method

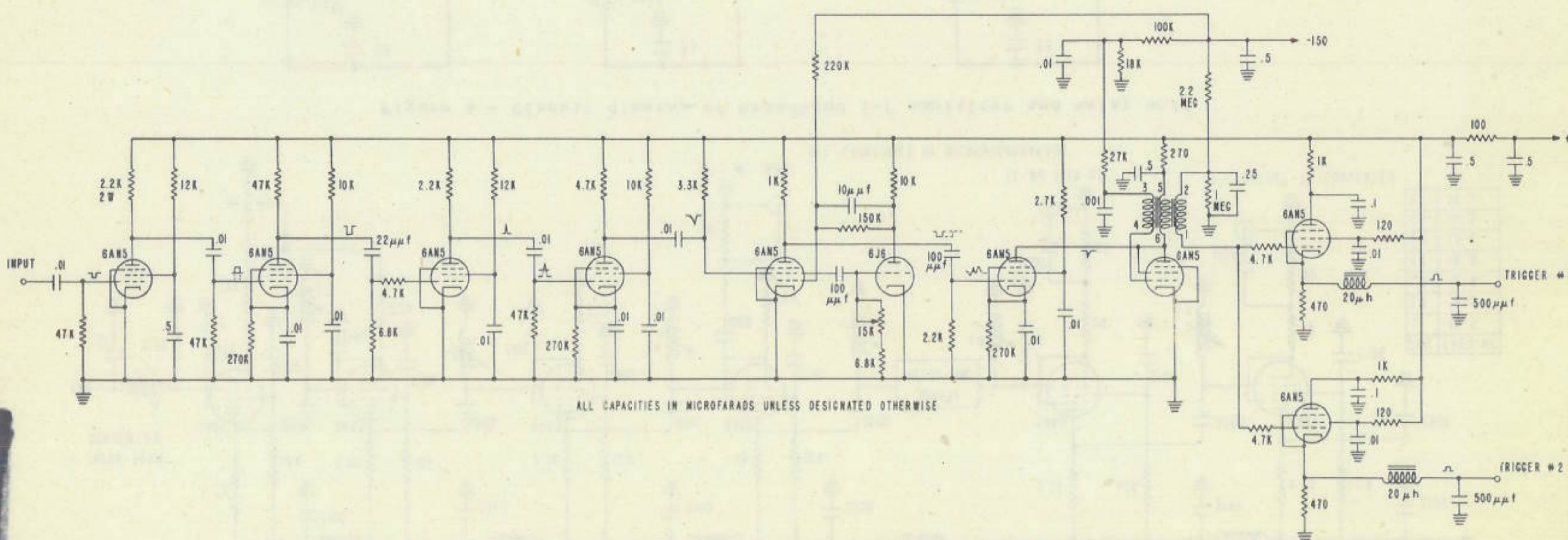

Figure 7 - Circuit diagram of trigger unit

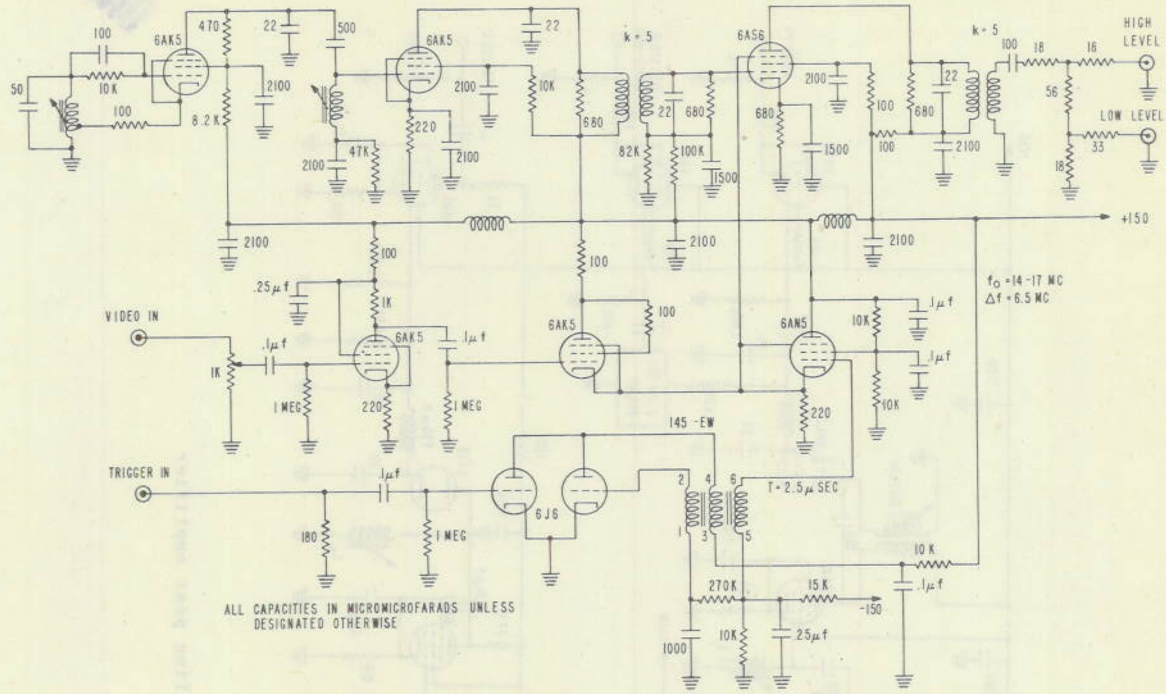

Figure 8 - Circuit diagram of remodulator unit

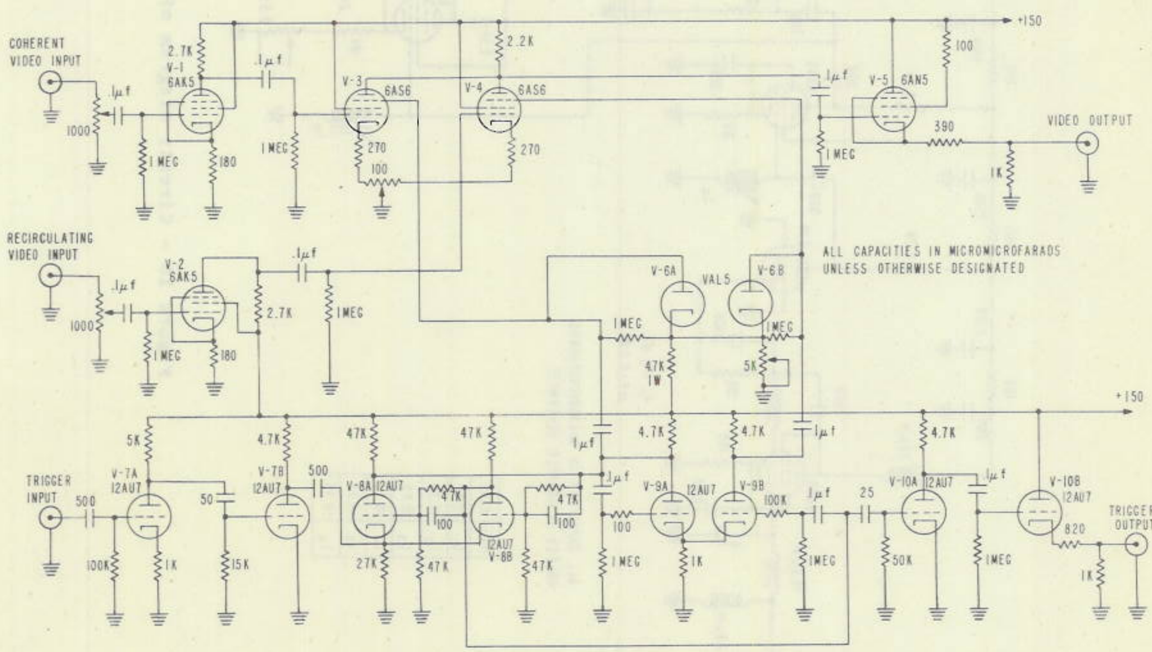

Figure 9 - Circuit diagram of video switch unit

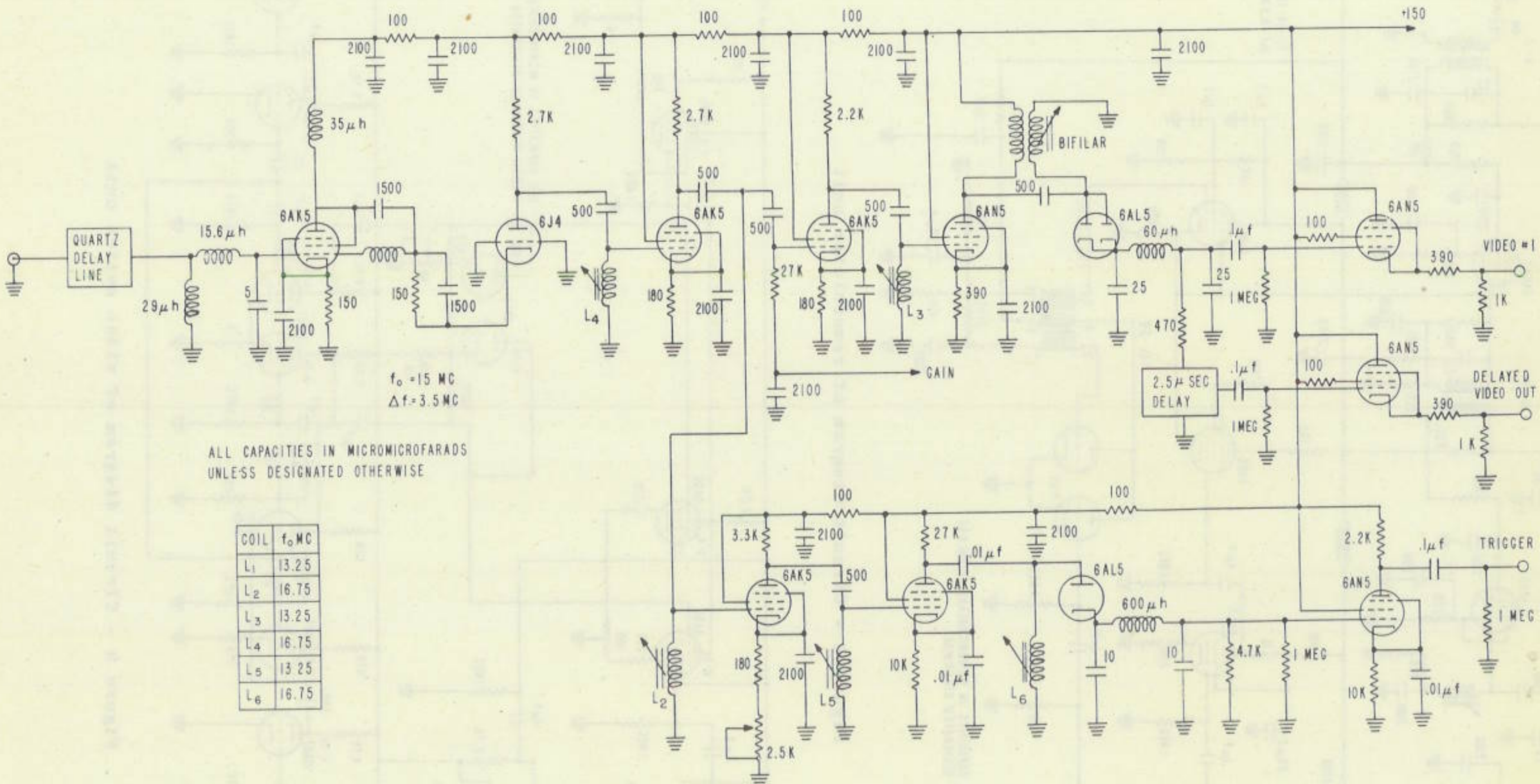

Figure 10 - Circuit diagram of delay-line post amplifier

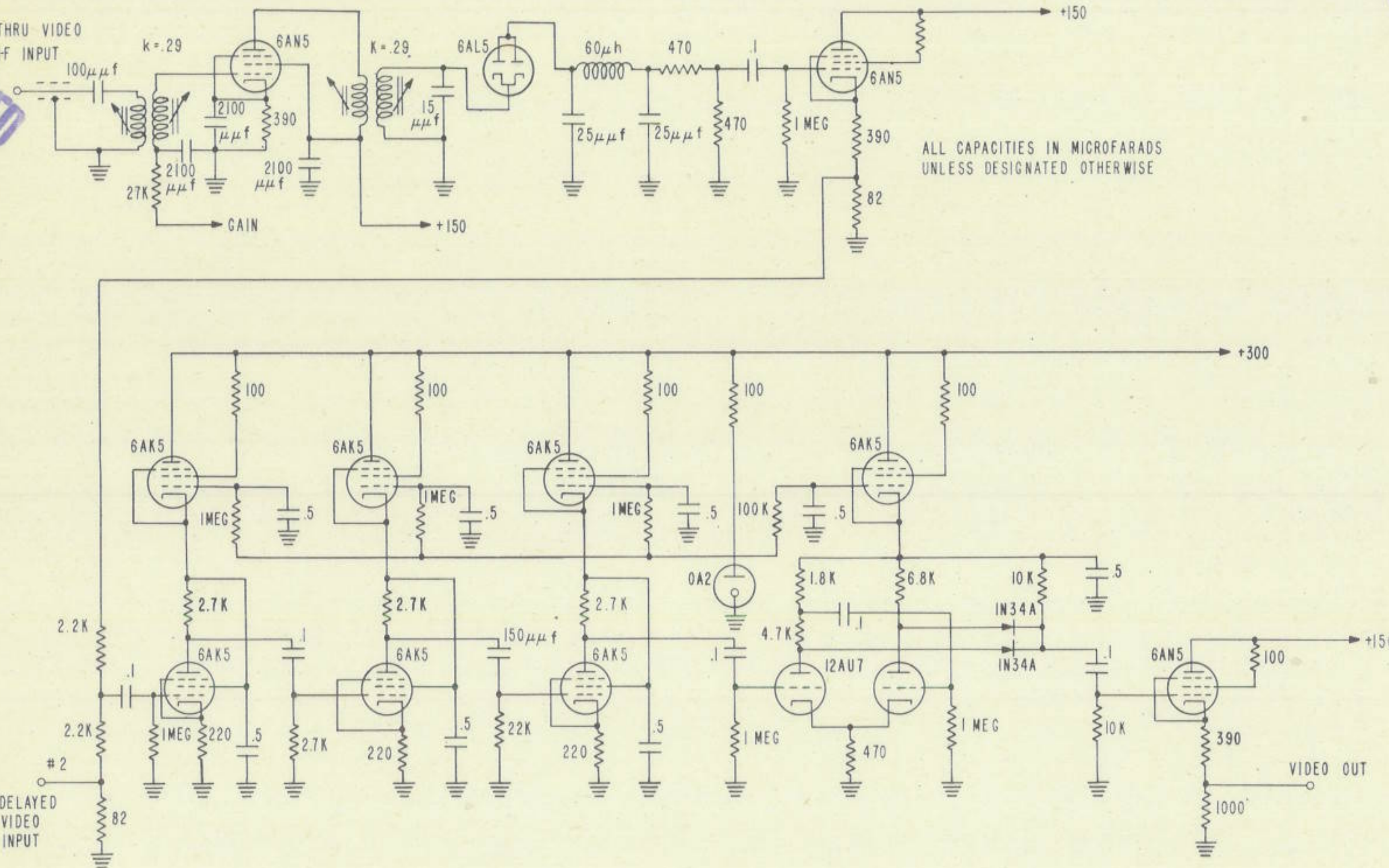

Figure 11 - Circuit diagram of thru video and cancellation unit

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